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A VACUUM ULTRAVIOLET PHOTOIONIZATION DETECTOR

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SUMMARY 13220

A small ceramic ion chamber has been developed for a rocket astronomy program in the vacuum ultraviolet. The chamber consists of a small metal plated ceramic shell incorporating a window of LiF, CaF_2 or BaF_2 and containing one of several fill gases such as nitric oxide, acetone, or carbon disulfide. Typical quantum efficiencies range from 8-10 percent for acetone with a CaF_2 window to 50-60 percent for carbon disulfide with a LiF window. Details of the chamber construction are given and some recent applications of the detector are described.

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INTRODUCTION

As part of a continuing program of astrophysical and geophysical observations in the vacuum ultraviolet wavelength region, a small ceramic photoionization chamber has been developed at Goddard Space Flight Center. This chamber, intended primarily for photodetection in the 1500A to 1050A region, has proved useful in a space science program which has included rocket and satellite borne measurements of solar and stellar fluxes and of upper atmospheric emissions.

Ion chambers and photon counters were first used in a series of rocket experiments carried on by the Naval Research Laboratory in the 1950's. The literature contains several accounts of these vacuum ultraviolet detectors (References 1 and 2), and the experimental results obtained from their use (References 2-5). When the space science program at Goddard Space Flight Center was established in 1959, the experience gained from use of these earlier photoionization detectors was employed to design the present chamber. A brief description of the NASA ion chamber appears in a view of current ultraviolet photodetector developments by Dunkelman (Reference 6).

DESIGN DETAILS

Gas ionization photodetectors have the useful properties of high spectral selectivity and relatively high quantum efficiencies. They can also be made very rugged and very compact. If meticulous attention is given to a number of fabrication details (Reference 7), the NASA ionization chamber can have a long "shelf life", and also the low noise and stability needed for measuring very small incident photon fluxes (100-1000 photons/sec). Specifically, electrical leakage between electrodes must be minimized: a 10^{15} ohm path is easily achieved; photoelectric emission from the chamber walls must be reduced; recontamination of the filling gas after purification must be avoided; and window and connector seals must hold a high vacuum—better than 10^{-6} torr. The NASA ion chamber (Figures 1 and 2) was designed to satisfy these requirements.

*Presented at the Los Angeles Meeting of the Optical Society of America, October, 1961.

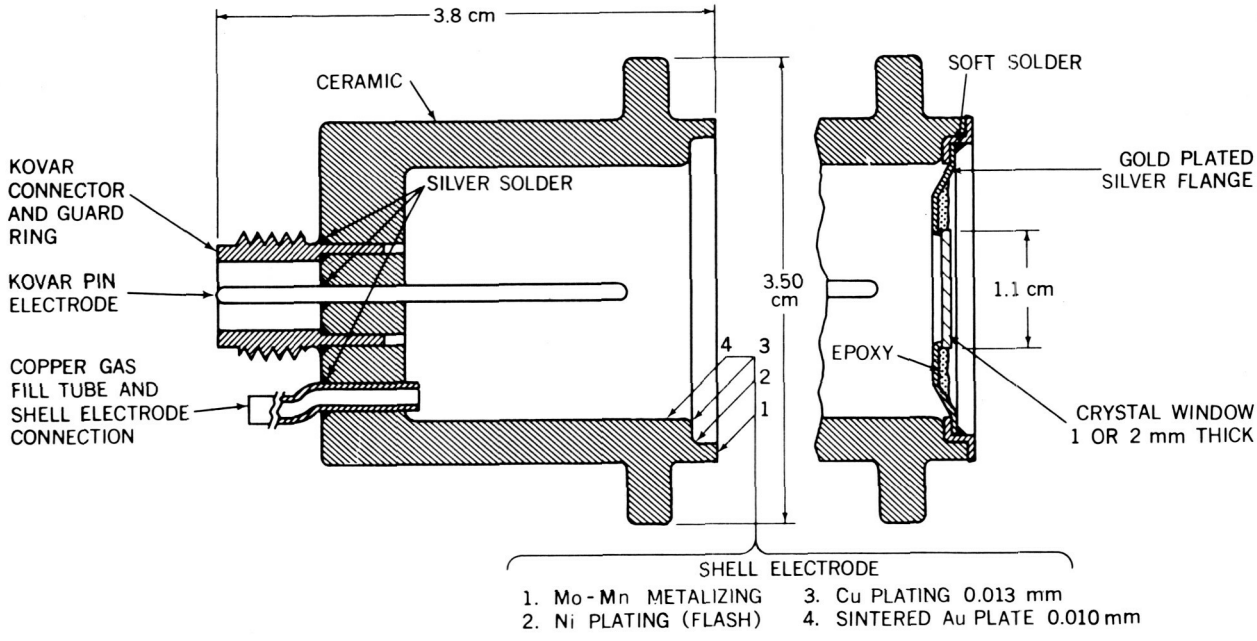

Figure 1—Cross section of the NASA ion chamber. The inside diameter is 1.9 cm and length 2.3 cm. Window materials are generally of LiF, CaF_2 or BaF_2 crystals.

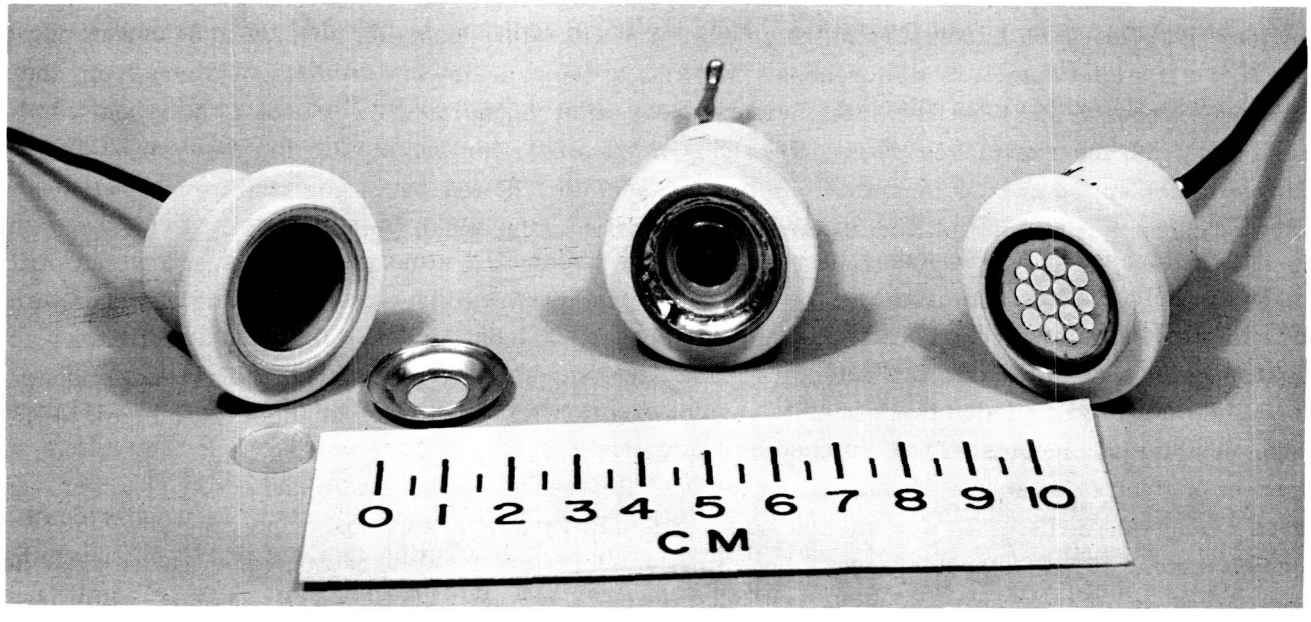

Figure 2—Three of the ceramic ion chambers. At left is an unfinished chamber with window and flange. In the center is a completed tube. At right is a tube with a thin aluminum window for x-ray use.

The chamber consists of a ceramic shell, gold plated on the inside, fitted with a highly polished central collecting wire electrode and incorporating a window of suitable transmission properties. This shell has an external lip to provide a surface for making an "0" ring seal into either the exit port of a vacuum monochromator or into the skin of a rocket or satellite package. It is usually fitted

with an 11-mm-diameter crystal window, and has an inside diameter of 1.9 cm and an inside length of 2.3 cm.*

The ceramic shell† itself is of a high density alumina; it is plated on the inside with several layers of metallic coatings, finishing with a gold plate on the surface, to form one of the electrodes. Brazed into the unplated rear face of the tube are a Kovar central pin electrode, a guard-ring and connector, and a copper gas-filling tube 10 cm long which also provides the electrical connection to the metal plated shell electrode.

The ion chamber window, usually consisting of 1 or 2 mm thick cleaved crystals of LiF, CaF_2 or BaF_2, is fastened to a thin gold-plated silver flange by an epoxy layer. The flange, whose 9.5 mm diameter defines the aperture of the chamber, is soft-soldered onto the metalized ceramic shell prior to forming the window seal. The sealed tube is baked at 100°C for several hours. While being heated to 200°C, the assembled chamber is evacuated through the copper gas fill tube until a pressure of 10^{-6} torr or less is reached. The filling gas, which has previously been distilled from a supply of commercial "pure" gas, is admitted through the tube and the chamber is sealed by pinching the copper tube closed and dipping its end in solder.

The choice of the ceramic chamber assures the desired ruggedness and low electrical leakage and provides a surface resistant to contamination. The gold plating on the chamber walls provides a conducting surface with low photoelectric emission and a high work function (Reference 8), and one that will not react with any of the chosen filling gases. In addition, by keeping the entrance window small and leaving the rear wall of unplated ceramic (except for the center pin, guard ring and gas filling tube), the amount of photoemissive surface exposed to the incident flux is kept to a minimum. The epoxy and soft-solder window seal has proved very tight and, since high temperature baking is not required, quite stable over long periods. The general success of these design features can be demonstrated by the almost zero rejection rate which has been achieved in assembly of chambers and by the existence in the GSFC laboratory of chambers assembled almost two years ago which still maintain their quantum efficiencies. A single exception appears to be a diethyl sulfide chamber with a BaF_2 window. These chambers have a spectral passband from 1350 to 1480A and an efficiency approaching 20 percent, but the few detectors made have had shelf lives of little more than a month. Investigations of gas purification and anti-recontamination are underway in the early stages of an attempt to increase the shelf life of this detector.

The short wavelength limit of the spectral response of the NASA ion chambers is usually determined by the transmission cutoff of the window materials. In addition to the LiF, CaF_2 and BaF_2 crystals mentioned earlier, windows of NaF or sapphire may also prove useful. The transmittance curves of these materials have been given by Dunkelman, Fowler, and Hennes (Reference 9). Also used with these ceramic ion chambers have been windows of thin (0.03-0.2 mm) foils of aluminum and beryllium. When used with a filling gas such as xenon, these ion chambers become useful x-ray detectors in the 2-8A region. Window materials and filling gases for use in either the vacuum ultraviolet or x-ray region have been tabulated by Friedman (Reference 2).

*Calibrated ceramic ion chambers of this design are now commercially available from the Geophysics Corporation of America, Bedford, Massachusetts.
†Manufactured by the Coors Porcelain Company, Golden, Colorado.

DETECTOR CHARACTERISTICS

In normal use, the ceramic ion chamber is operated with the guard ring at ground potential and the shell electrode at −45 to −90 volts, depending on the gas filling. When it is necessary to suppress photoelectric emission from the walls completely, the shell electrode is operated at a positive potential. In many applications, however, the available flux is so exceedingly small that is is necessary to operate these tubes as gas gain detectors. If the collecting voltage is raised past the low voltage plateau region the output current increases in an exponential fashion. Gains of 1000 are generally attainable with voltages of 600 to 800 volts. The shell electrode carries the negative high voltage in this case.

A variety of filling gases have been used with these tubes. The choice of the gases is determined by the spectral region of experimental interest and, of course, it fixes the long wavelength cutoff. The stability of the gas when incorporated in an ion chamber determines whether any specific gas can make a useful detector. Figure 3 shows the spectral response of five of the gas-window combinations which have been used in ion chambers in rocket borne experiments by GSFC. The curves represent smoothed values of quantum efficiency as measured on a McPherson one-meter vacuum monochromator operating with a resolution of 3-4A. Some of the fine structure of nitric oxide is shown in curve 3 but most of the details do not appear (References 10, 11, and 12). Of particular interest are the relatively narrow response bands, and the fairly high quantum yields. The measured quantum efficiency of any given chamber is a combination of the actual photoionization yield of the gas, the transmittance of the window, and the absorption efficiency and ion collection efficiency of the chamber.

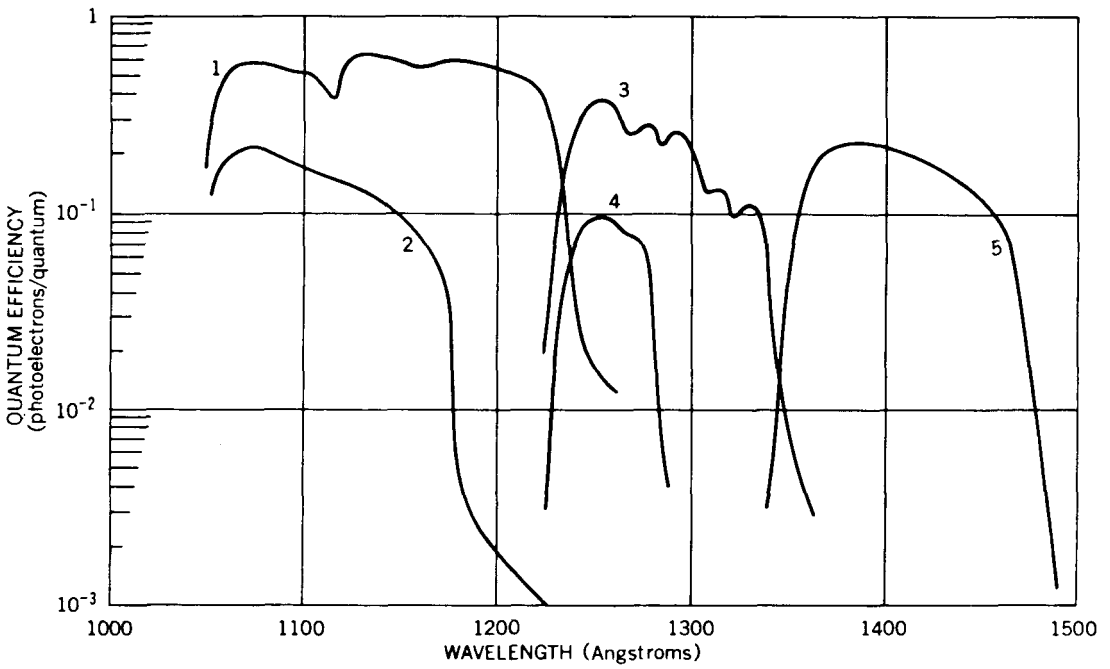

Figure 3—Typical ion chamber spectral response curves for several gas and window combinations. Smoothed curves are shown although a certain amount of fine structure is obscured in so doing: (1) carbon disulfide with LiF window; (2) ethylene oxide with LiF window; (3) nitric oxide with CaF_2 window; (4) acetone with CaF_2 window; (5) diethyl sulfide with BaF_2 window.

Table 1 lists some of the gas and window combinations used in the GSFC space science program and gives some of the most pertinent features of these ion chambers.

Table 1

Typical NASA Ion Chamber Characteristics

Filling Gas	Chemical Formula	Gas Pressure (torr)	Window Material	Window Thickness (mm)	Spectral Response Region (Angstroms)	Typical Quantum Yields* $\left(\frac{\text{photoelectrons}}{\text{photon}}\right)$
Diethyl Sulfide	$(C_2H_5)_2S$	5	BaF_2	1	1350 - 1480	0.10 - 0.20
Nitric Oxide	NO	20	CaF_2	1	1230 - 1350	0.20 - 0.30
Nitric Oxide	NO	20	LiF	1	1050 - 1350	0.30 - 0.40
Acetone	CH_3COCH_3	4.5	CaF_2	1	1230 - 1290	0.08 - 0.10
Carbon Disulfide	CS_2	15	LiF	1	1050 - 1240	0.50 - 0.60
Ethylene Oxide	$(CH_2)_20$	4.5	LiF	1	1050 - 1180	0.10 - 0.20
Xenon	Xe	775	Be	0.13	2 - 8	Not measured

*Based on an absolute photoionization yield of 0.81 ion pairs/photon for NO at Lyman-α.

CALIBRATION

The shapes of the spectral response curves (Figure 3) of the detectors are determined by comparing the given chamber's response to a hydrogen arc lamp with the response of a sodium salicylated detector to the same lamp. The fluorescence yield of sodium salicylate is assumed to be fairly constant over this wavelength region from 1500A to 1000A (Reference 13). Measurements were made at the exit slit of the 1-meter vacuum monochromator mentioned earlier. Absolute quantum yield values were determined by directly comparing the signal from the ion chamber in question, when exposed to Lyman alpha (1216A) radiation, with the signal from a reference "standard" ion chamber (Reference 7) exposed to the same beam. The reference ion chamber is a large-volume windowless glass cylinder containing large, flat, plane-parallel collecting electrodes for both efficient absorption of the incident flux and efficient collection of the ion-pairs produced. The electrodes are rigidly mounted to avoid vibration pickup.

Calibration of the ion chamber quantum efficiencies is based on the absolute photoionization yield of nitric oxide (NO) at the Lyman alpha wavelength. From the work of K. Watanabe (private communication) this yield is taken to be 0.81 ion-pair per photon. The flat sodium salicylate response is used to transfer the quantum efficiency measurements from Lyman alpha to other wavelengths when the efficiency of the gas being measured is required for wavelengths other than Lyman alpha.

APPLICATIONS

The NASA ceramic ion chambers were first used successfully in the spring of 1960 in a series of Aerobee-Hi rocket experiments designed to survey the northern night sky (Reference 14 and

private communication from A. Boggess III, J. E. Milligan, and T. P. Stecher). Ion chambers containing nitric oxide, acetone or carbon disulfide were positioned at the foci of 10-cm-diameter collecting mirrors which scanned the sky as the rocket rolled and precessed. Because of the weak signals expected from stellar sources the ion chambers were operated with gas gains of about 200. The signals observed were on the order of 10^{-12} ampere with this system, indicating a flux of about 10^{-7} erg/sec-cm^2.

In August-November 1961, a similar survey of the southern hemisphere night sky was obtained from a series of Skylark rocket firings from Woomera, Australia (Reference 15 and private communication from A. Boggess III, R. Scolnik, R. M. Windsor). A single rocket carried four ion chamber telescopes, each consisting of two chambers located alongside one another at the focus of a 15-cm-diameter mirror. Useful signals were obtained from about 60 stars with the ion chambers operating at gas gains of 300-500.

Figure 4 shows 3 seconds of a typical telemetry record from this flight. The top and bottom channels represent middle ultraviolet photomultiplier photometers and the middle one an ion chamber telescope. The difference in noise level between the two types of detector is evident. Three double-peaked ion chamber signals are apparent, representing the sweep of the ion chamber telescope across three stars as the rocket slowly turned. The asymmetry of the right and left parts of each double-peak is produced by the off-axis location of the ion chambers, which causes the effective mirror aperture to change as the star moves across the field of view. The double peak itself is a function of the position of the highly convergent beam in the ion chamber cavity. When the ion chamber is operated in a collimated beam the angular response to a point source is more or less flat-topped. When the chamber is operated in a highly focused beam the central region of the signal showing the telescope angular response may be depressed by as much as 75 percent. The choice of focus conditions presents different problems which the experimenter must resolve for himself.

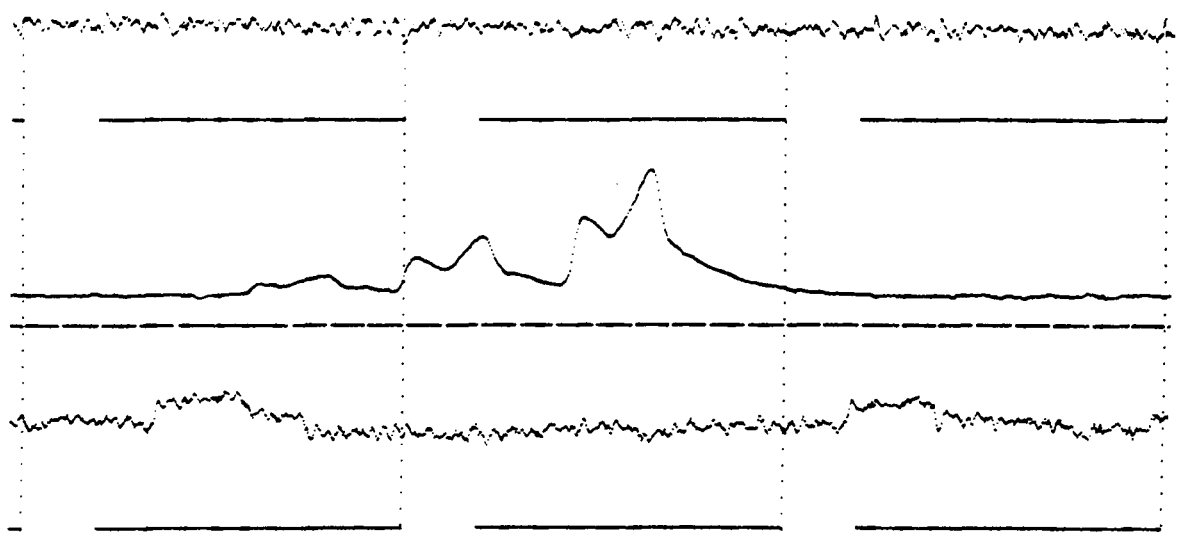

Figure 4—Telemetry record showing a 3-second portion of several detector signals: the top and bottom channels are signals from photomultiplier photometers; the middle channel is the signal from an ion chamber telescope.

More recently these ion chambers have been used in the first Orbiting Solar Observatory (1962 ζ 1) to observe the sun in two wavelength regions. One chamber, of nitric oxide with a LiF window, periodically observed the solar Lyman alpha emission from behind an aperture of about 0.4 mm diameter. Two others, operated in parallel with 0.13 mm thick beryllium windows and xenon gas, continuously measured the sun's x-ray emission in the 2A to 8A region. Other recent uses include a rocket borne ion chamber for measurement of the Lyman alpha radiation emitted from the top of the earth's atmosphere, and a Lyman alpha detector in an ionosphere probe to measure the rate of photoionization in the D region.

Perhaps the most important use for these detectors is as stable vacuum ultraviolet photodetectors for laboratory purposes. By combining the simple physical principles of gas ionization with a vacuum-tight and stable chamber, a very useful reference standard for laboratory spectroscopy can be obtained.

ACKNOWLEDGMENTS

The basic ion chamber design was suggested by J. E. Kupperian, Jr.; the use of a ceramic shell was suggested by E. V. Serra; the choice of an epoxy was suggested by W. A. Gallo, Jr.; E. V. Serra assisted in the development of the epoxy window sealing technique.

REFERENCES

1. Chubb, T. A. and Friedman, H., "Photon Counters for the Far Ultraviolet," *Rev. Sci. Instr.* 26 (5):493-498, May 1955.
2. Friedman, H., "The Sun's Ionizing Radiations," in: *Physics of the Upper Atmosphere,* ed. by J. A. Ratcliffe, New York: Academic Press, 1960, pp. 133-218.
3. Byram, E. T., Chubb, T. A., et al., "Far Ultra-Violet Radiation in the Night Sky," in: *The Threshold of Space: Proc. Conf. on Chemical Aeronomy, Cambridge, Mass., June 1956,* ed. by M. Zelikoff, New York: Pergamon Press, 1957, pp. 203-210.
4. Kupperian, J. E., Jr., Boggess, A., III, and Milligan, J. E., "Observational Astrophysics from Rockets. I. Nebular Photometry at 1300 A," *Astrophys. J.* 128(3):453-464, November 1958.
5. Byram, E. T., Chubb, T. A., et al., "Intensity of Solar Lyman-Alpha and Adjacent Ultraviolet Emission Lines," *Astrophys. J.* 128(3):738-741, November 1958.
6. Dunkelman, L., "Ultraviolet Photodetectors," *J. Quant. Spectr. and Radiative Transfer* (In Press).
7. Stober, A. K., "Ceramic Vacuum Ultraviolet Ion Chambers," NASA Technical Note D-1180, March 1962.
8. Childs, C. B., "Quantum Yield of Gold-Cathode Photomultipliers," *J. Opt. Soc. Amer.* 51(5):583, May 1961.
9. Dunkelman, L., Fowler, W. B., and Hennes, J. P., "Spectrally Selective Photodetectors for the Middle and Vacuum Ultraviolet," *Appl. Optics* 1(6):695-700, November 1962.

10. Watanabe, K., Marmo, F. F., and Inn, E. C. Y., "Photoionization Cross Section of Nitric Oxide," *Phys. Rev.* 91(5):1155-1158, September 1, 1953.

11. Marmo, F. F., "Absorption Coefficients of Nitrogen Oxide in the Vacuum Ultraviolet," *J. Opt. Soc. Amer.* 43(12):1186-1190, December 1953.

12. Watanabe, K., "Photoionization and Total Absorption Cross Section of Gases. Ionization Potentials of Several Molecules. Cross Sections of NH and NO," *J. Chem. Phys.* 22(9):1564-1570, September 1954.

13. Watanabe, K., and Inn, E. C. Y., "Intensity Measurements in the Vacuum Ultraviolet," *J. Opt. Soc. Amer.* 43(1):32-35, January 1953.

14. Boggess, A., III, "Ultraviolet Astronomical Photometry from Rockets," in: *Space Astrophysics*, ed. by W. Liller, New York: McGraw-Hill, 1961, pp. 121-132. Also published as NASA Technical Note D-673, June 1962.

15. Windsor, R. M., "The Southern Sky Survey Payload," NASA Technical Note D-1719. In press, 1963.